Recent Developments in Integrated Exhaust Emission Control Technologies Including Retrofit of Off-Road Diesel Vehicles

Manufacturers of Emission Controls Association

California Air Resources Board

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Presentation Outline

- Introduction
- Background
- Control Technologies for PM and Toxic Emissions
- Control Technologies for NOx Emissions
- Integrated Control Systems
- Retrofit Opportunities
- Conclusions

The Emission Challenge Is Complex

- Current Standards Focus on HC, NOx, PM, and CO
- However:
  - Toxic Emissions Are Obtaining More Attention
  - Particle Number Issues
  - Three Major Species of NOx
  - PM
    - many species, size range <10 nm to >2 microns, number, liquid and gaseous HCs, solid carbon, carbon/organic combinations and sulfur oxides

Can All Facets of the Diesel Emissions Issue Be Addressed?

- Are Control Technologies Available to Remove Both Diesel PM and the Other HC-Based Toxic Emissions?
- Are These Control Strategies Compatible with Further Reductions in NOx Emissions?

Yes, If an Integrated Approach Is Used -

Advanced Engines, Integrated Emission Control Technologies, and Clean Fuels

Existing Technologies Provide Many Options and Emerging Technologies Show Much Promise

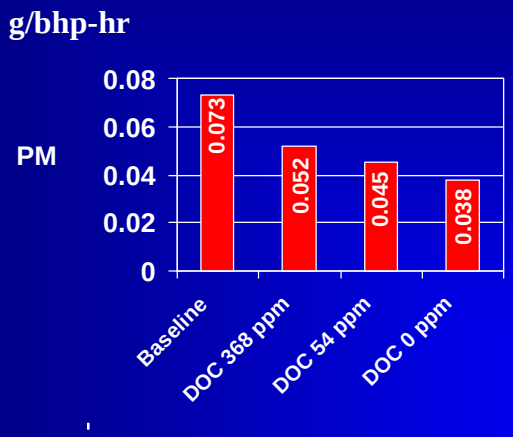
- Existing Emission Controls Can Greatly Reduce Diesel Emissions
  - Oxidation Catalysts, Particulate Filters, Fuel-Borne Catalysts in Combination with Exhaust Controls, Coatings, Modified Engine Components
- Advanced Emission Control Technologies
  - NOx Catalysts, SCR, Plasma Technology, NOx Adsorbers, Combined Systems
- New Engine Technologies
  - Common Rail or Unit Injection, Cooled EGR, Advanced Fuel Spray, Pilot Injections, Variable Geometry Turbocharging
- Advanced Fuels
  - Low Sulfur, Low Aromatics, Other Properties

Integrated Emission Control Will Allow Diesel Engines to Meet the Future Challenges

Diesel Oxidation Catalysts Are Efficient and Have Excellent Operating Experience

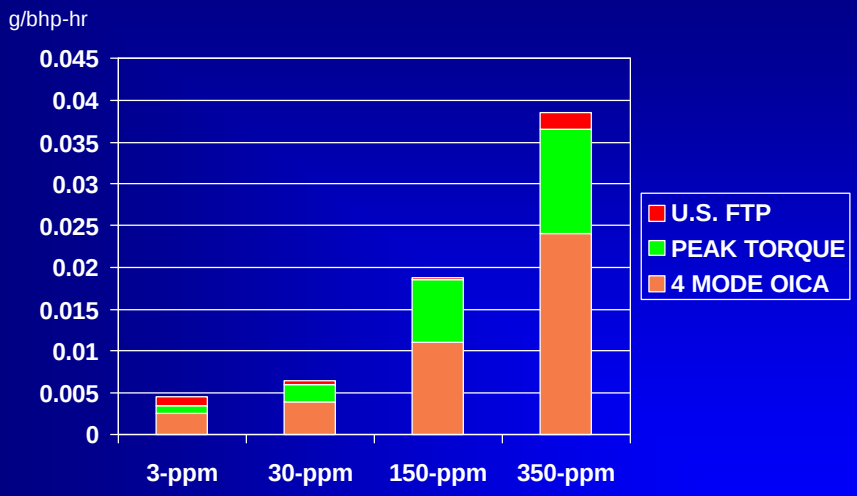
- Oxidation Catalyst Control Capabilities
  - PM -- 20-50% Reduction
  - CO and HC -- >90%
  - Toxic HCs -- >70%
- Oxidation Catalyst Operating Experience
  - >5,000,000 Light-Duty Vehicles in Europe
  - >1.5 Million HDEs in the U.S.
  - >250,000 Nonroad Engines

Diesel Oxidation Catalysts Are More Effective When Used with Low Sulfur Fuel



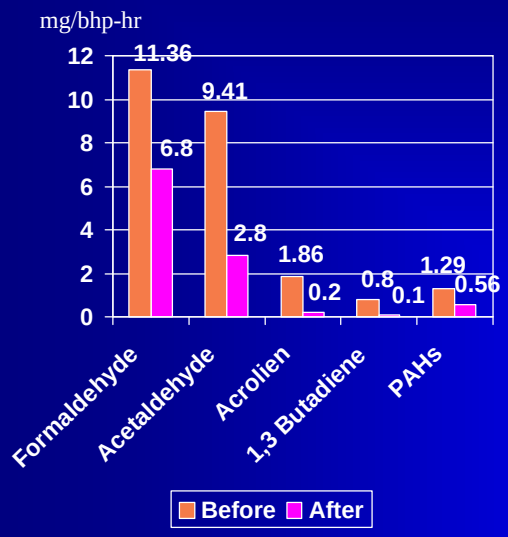
Source: MECA 1999

Break Specific SO4 Emissions over Different Test Cycles Can Be Significant when Using an Oxidation Catalyst



Source: DECSE 1999

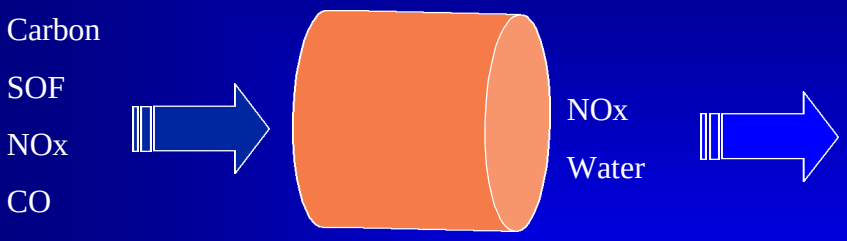
Oxidation Catalysts Destroy Large Fractions of Toxic Emissions



- Toxic Hydrocarbon Compounds Reduced by 68%
- PAH Emissions Reduced by 56%
- 368 ppm Sulfur Fuel

Source: MECA 1999

Diesel Particulate Filters Address Most Controlled Emissions

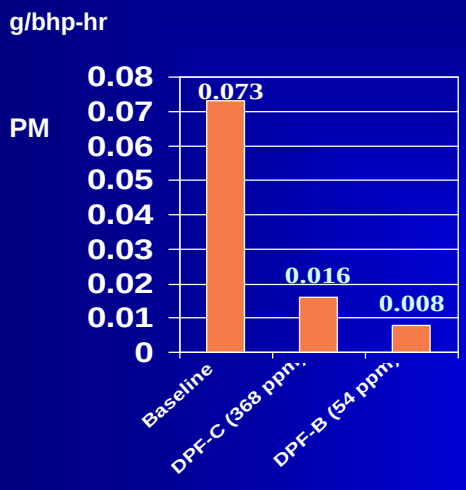


Diesel Particulate Filters Trap Carbon and Adsorbed SOF and Can Be Used to Oxidize CO, and HC to Reduce PM, CO, HC, and Toxic Emissions.

Diesel Particulate Filters Are Efficient and Are Developing an Impressive Track Record

- Filter Control Capabilities
  - PM -- >80% Reduction
  - CO and HC -- >90%
  - Toxic HCs -- >90% Reduction
- Based Filter Operating Experience
  - Several Thousand Trucks and Buses in Commercial, Retrofit Operation in Europe
  - Peugeot Will Offer Filter-Equipped LDVs in 2000
  - Over 10,000 Non-Road Engines Equipped (Both OE Installed and Retrofit)

Diesel Particulate Filters Nearly Eliminate PM



- PM Emissions Well Below 0.02 g/bhp-hr Can Be Achieved on Both Fuels (0.008 with 54 ppm S Fuel)
- Significant Reductions in CO and HC Emissions Can Be Achieved

Source: MECA 1999

The VERT Study on LDD & Off Road HDD Showed DPFs Significantly Reduce PM and Gaseous Emissions

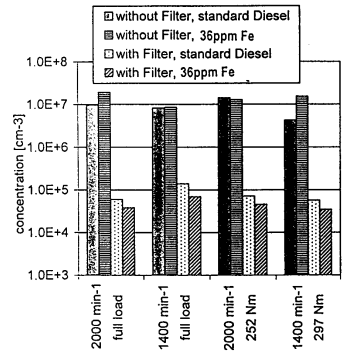


Fig. 14: Concentration count integrated in the range 20 - 200 nm

Filters reduced PM by more than 99% by number at all load points

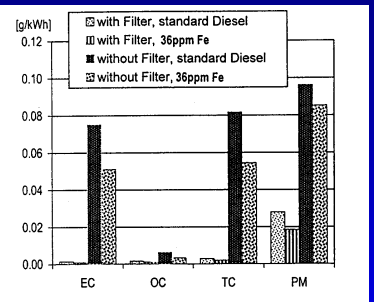


Fig. 15: CAT4 filter function according to Coulometry

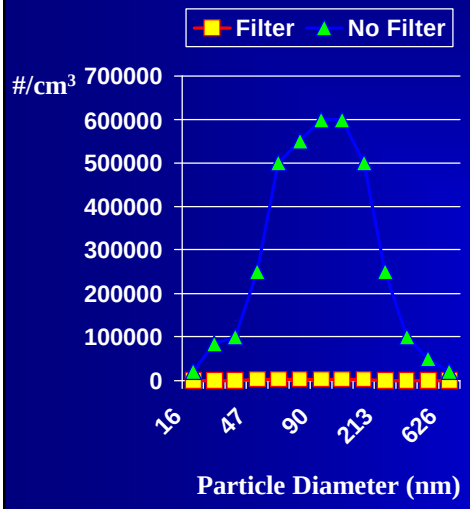
Only the newer sensor technology [7] facilitates particulate counting during transients. The results confirm that filtration rates of 99% and more can be attained under transients, too.

Filters reduced PM by 99%+ by number, but only 70% by mass

EC: elemental C
OC: organic C

Source: VERT SAE 1999-01-0116

Filters Very Effective in Reducing Ultra-Fine Particles



- Ultra-Fine Particles Reduced by in Excess of 99.99 %

Source: VERT 1998

The DECSE Study Is Showing That 20 ppm or Lower Sulfur Is Needed to Achieve 0.01 g/bhp-hr

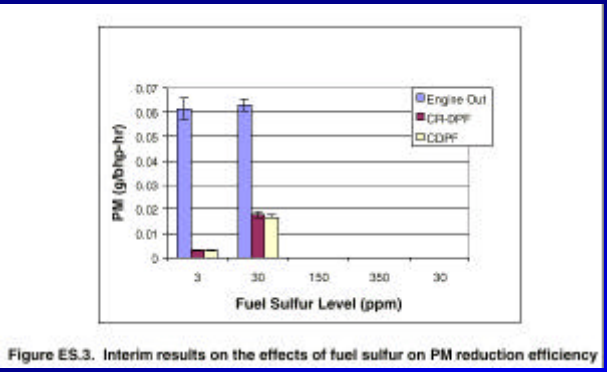


Figure ES.3. Interim results on the effects of fuel sulfur on PM reduction efficiency

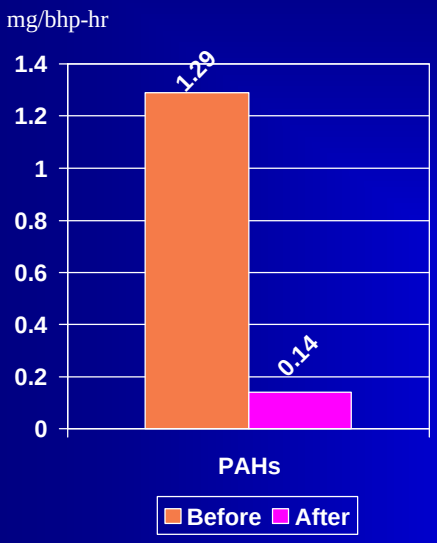
OICA 13-mode cycle; CAT 3126 engine

95% filtration efficiency at 3 ppm sulfur
74% filtration efficiency at 30 ppm sulfur

At these low levels of emissions, sulfuric acid is likely the majority of PM - 100 ppm sulfur equals 0.055 g/bhp-hr sulfuric acid by simple mass balance. To achieve 0.01 g/bhp-hr, <20 ppm sulfur will be needed.

Source: DECSE 1999

Filters Destroy Large Fractions of Toxic Emissions



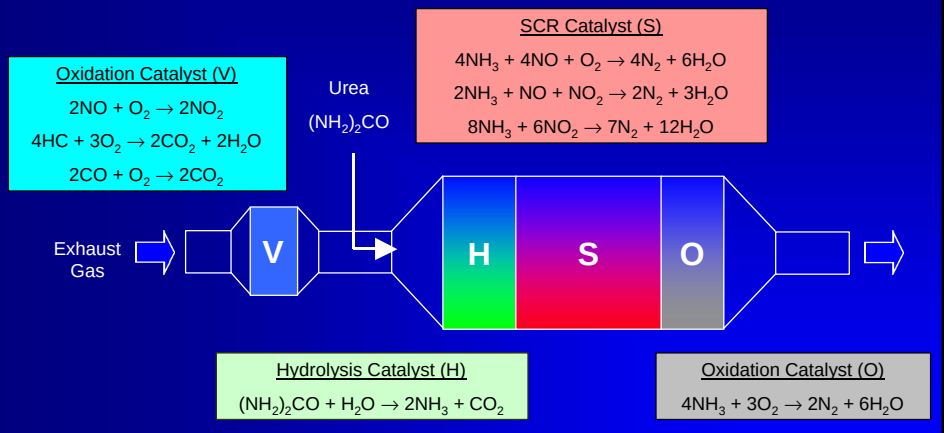
- PAH Emissions Reduced by 89%

Source: MECA 1999

NOx Technology Concepts Overview

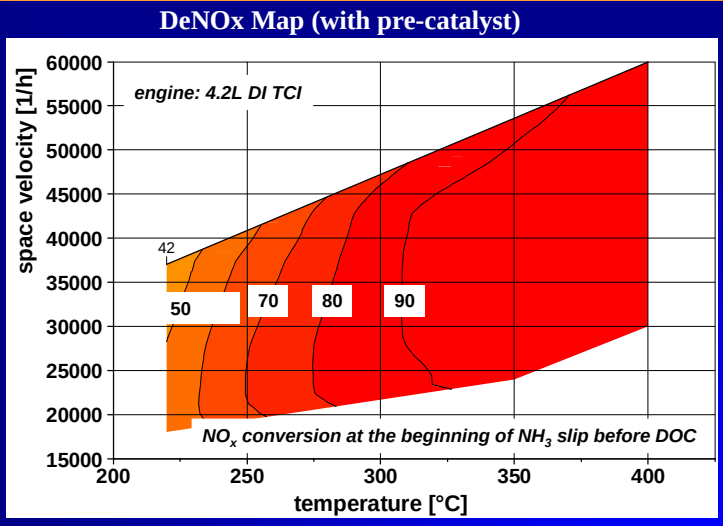
Technology	Performance Range				Potential Commercial Availability
	NOx	CO	HC	PM	
Active Lean NOx	25-50	>70	>70	~ 30	2000
NOx Adsorber	50-70	>70	>70	> 30	2004
SCR Urea	>80	>50	>70	≥ 30	2000
Compact SCR	>90	>70	>70	≥ 30	2004
Plasma / NOx Cat.	>65	>50	>50	~ 30	Post - 2004

State-of-The Art SCR System has NO2 Generation and Oxidation Catalyst to Eliminate Ammonia Slip



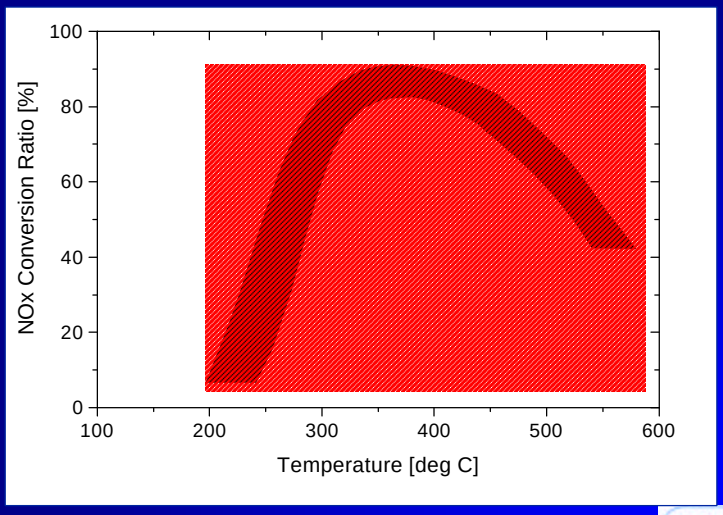
Source: Schaefer-Sindlinger, Degussa, 9-99

SCR Systems Can Achieve 80+% Efficiency under Reasonable Conditions



Source: Schaefer-Sindlinger, Degussa 9-99

NO_x Adsorber Conversion Ratios Are Getting into the High-80% Efficiencies at Reasonable Temperatures



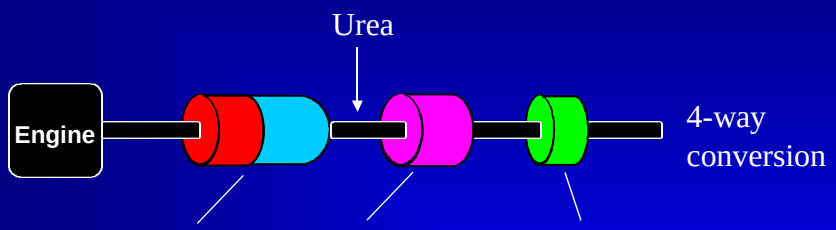
Source: Geckler, FEV, 9-99

NOx Technologies Are in Various Stages of Development

- Passive Lean-NOx Catalysts Used on PC in Europe
- SCR Used on Stationary Sources, Marine Vessels, Locomotives and Have Been Used in Truck and PC Demonstration Programs
- NOx Adsorbers Are in Vehicle Trials
- Plasma Technology Is in the Laboratory Stage and Emerging on Vehicles

Examples of Integrated Systems

Integrated System Using a DOC, DPF, and SCR



CATALYST/FILTER

Removal of HC, CO, PM

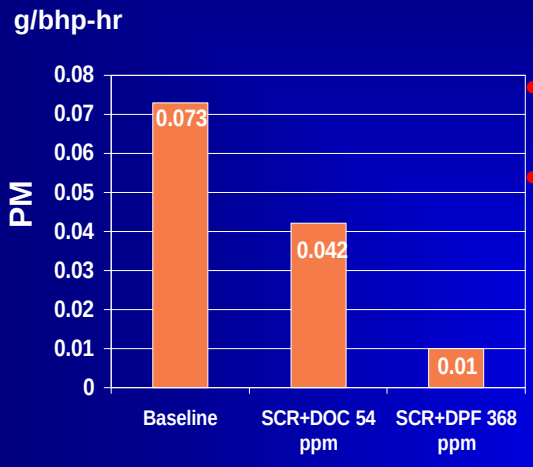
SCR

Removal of NOx

Oxidation Cat

Removal of NH_3 slip if required

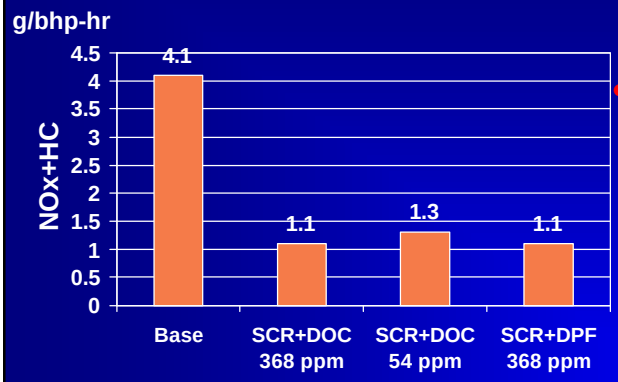
DOC and DPF Performance With SCR Can Reduce PM Emissions to Low Levels



- PM Emission Levels of 0.01 g/bhp-hr with DPF Technology using 368 ppm S fuel
- PM Emissions less than 0.05 g/bhp-hr Can Be Achieved with DOC Technology and 54 ppm S Fuel

Source: MECA 1999

SCR With DOC and DPF Performance Shows Very Effective NOx Performance

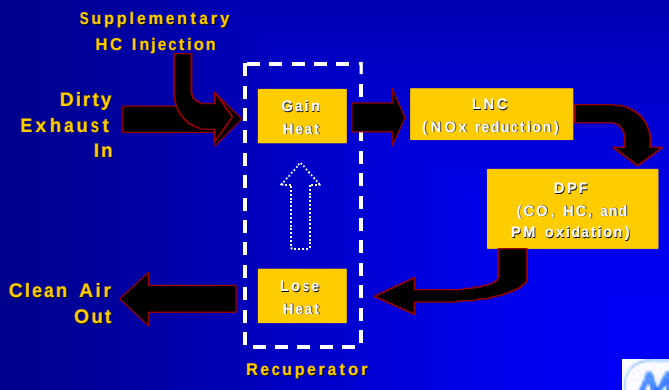


- Combined with the Low PM Emissions, NOx + HC Levels Below 1.5 g/bhp-hr NOx Can Be Achieved on 368 ppm S Fuels

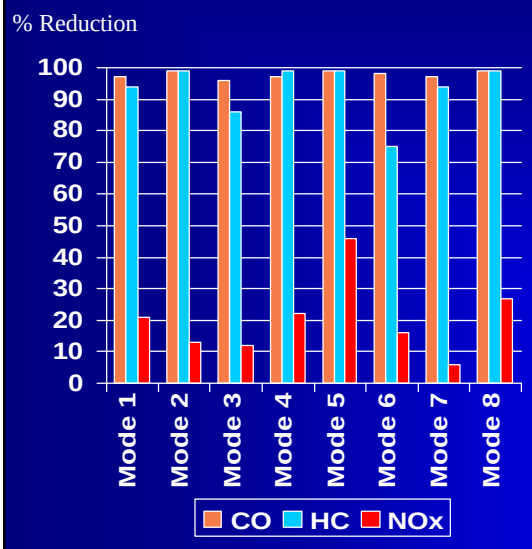
Source: MECA 1999

Integrated System – Lean NOx Catalysis + Filter

Integrate heat transfer and chemistry for simultaneous reduction of NOx, CO, HC, & PM



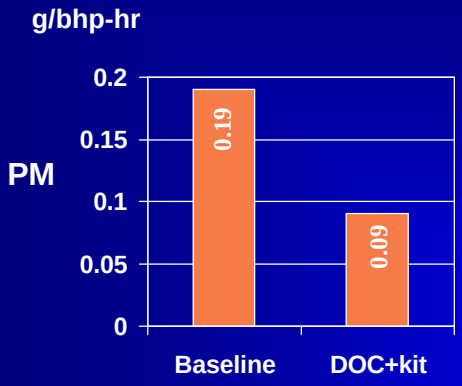
Greater Than 90% HC and CO Reductions Were Achieved at Most Load Points With 10 to 40% NOx Reductions with the Previous System



- Reductions in CO, NOx, and HC Were Achieved

Source: SAE Paper 1999-01-2924

Diesel Oxidation Catalysts Combined with an Electrically-Powered Supercharger Reduce PM Emissions



- A 50 % Reduction in PM Emissions Can Be Achieved

Source: MECA 1999

Diesel Retrofit Opportunities

-- PM and Toxics

-- NOx

-- Stationary Engines

Available Retrofit Technologies

- PM and Toxics (including CO and HC)
  - Diesel Oxidation Catalyst (DOC)
  - Diesel Particulate Filters (DPF)
  - Enhanced Combustion Modifications (e.g., cams, coatings, superchargers)
  - Biodiesel and Alternative Fuels (used with DOC)
  - Fuel Borne Catalysts with Exhaust Emission Controls

Available Retrofit Technologies (cont'd)

- NOx
  - Urea SCR (may provide reduction in other pollutants as well)
  - Systems Strategies (engine modifications plus PM exhaust controls)

Emissions Reductions of Retrofit Technologies

Technology	PM Reduction	NOx Reduction	HC Reduction	CO Reduction
DPF	>90%	n.a.	>90%	>90%
DOC	>30%	n.a.	>90%	>90%
SCR	>30%	>80%	>70%	>50%
Supercharger	20%	n.a.	n.a.	n.a.

Retrofit Experience

- Mining
  - >5,000 Filters
  - 10's of Thousands of DOCs
- Materials Handling
  - >5,000 Filters
  - 100's of Thousands DOCs
- Truck and Bus
  - ~10,000 Filters
  - >10,000 DOCs

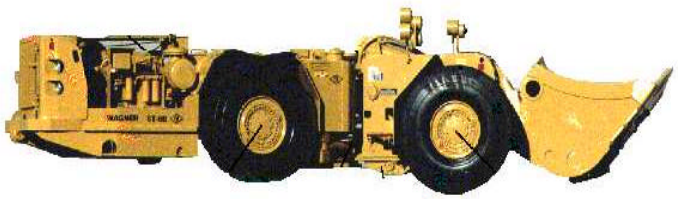
Retrofit Experience (cont'd)

- Other Applications
  - SCR on Marine Vessels, Locomotives, Trucks, and Stationary Engines
  - DOCs on Stationary Diesel Engines
  - Filters on Stationary Diesel Engines

Both Oxidation Catalysts and Diesel Particulate Filters Have Been Extensively Retrofitted to This Type of Mining Vehicle

Both Oxidation Catalysts and Diesel Particulate Filters Have Been Extensively Retrofitted to This Type of Mining Vehicle

ST8-B Scooptram



Testing of An Oxidation Catalyst on a FEL

Central Artery/Tunnel Project (Big Dig)

Conclusions

- Heavy-Duty Diesel Engines Are a Significant and Growing Source of NOx, PM, and Toxic Emissions
- A Variety of Demonstrated Technologies are Available to Significantly Reduce Emissions from Both New and Existing HDDEs
- A Growing Number of Retrofit Programs Are Being Successfully Implemented

Conclusions (cont'd)

- Diesel Emission Control Technologies Are Effective in Reducing PM, NOx, HC, CO, Odor, Smoke, and Toxics Emissions